FEATURE

Energy Efficiency Opportunities in Electric Arc Steelmaking

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In 1994, the U.S. manufacturing sector consumed 26 EJ (24.7 quads) of primary energy, almost one-quarter of all energy consumed that year.[1] A subset of U.S. raw materials transformation industries (primary metals, pulp and paper, cement, chemicals and petroleum refining) require more energy to produce a unit of output when compared with the average energy requirement of the manufacturing sector.

An in-depth analysis of the U.S. iron and steel industry identifies cost-effective energy and carbon savings that can be achieved today and in the near future.

This paper reflects an in-depth analysis of one of these energy-intensive industries – iron and steel – identifying cost-effective energy and carbon savings that can be achieved today and in the near future.[2]

The paper first will discuss trends in the production and energy use industry at the aggregate level [Standard Industrial Classification (SIC) 331 and 332], which includes blast furnaces and steel mills (SIC 3312), electrometallurgical products (SIC 3313) and gray and ductile iron foundries (SIC 3321). Second, it will discuss trends in U.S. steel industry energy intensities from an international perspective. Third, it will focus on a smaller portion of the industry – electric arc steelmaking – for a detailed analysis of energy use and carbon emissions, and technologies and practices to reduce these items. This will be followed by an analysis of the potential for energy efficiency and carbon emissions reduction from steelmaking in the United States. The paper will close with a discussion of innovative policies for energy efficiency improvement as used by some European countries.

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TRENDS IN THE U.S. STEEL INDUSTRY

The U.S. iron and steel industry is composed of integrated steel mills that use a blast furnace and basic oxygen furnace (BOF) to produce steel, and electric steel mills that use an electric arc furnace (EAF) to produce steel from scrap steel or direct reduced iron (DRI). Integrated mills produce the majority of steel in the United States, although the share produced by electric steel mills is increasing, growing from 15 percent of total steel production in 1970 to 40 percent in 1995.[3]

In 1997, 142 steel plants were operating in the United States. Fourteen steel companies operated 20 integrated steel mills with a total of 40 blast furnaces.[4] These mills are concentrated in the Great Lakes region, near supplies of coal and iron ore and key customers such as automobile manufacturers. The blast furnaces in these mills range in age from two to 67 years (including furnace rebuilds), with an average age of 29 years. Production rates vary between 500,000 and 3.1 million metric tons (mmt) per year. Total production of U.S. blast furnaces in 1997 was slightly more than 54 mmt (1 mt equals 1.1 short ton).[4]

Electric steel mills are located throughout the United States, with some concentration in the South, near waterways for shipping and in areas with lower cost electricity.[5] The largest number of plants are in Pennsylvania, Ohio and Texas. In 1997, 85 electric steel companies operated 122 mills with 226 EAFs in 35 states. The electric arc furnaces at these mills range in age from zero (just starting production in 1997) to 74 years, with an average age of 24 years. Total annual nominal capacity listed in 1994 was 50.4 mmt, and the average rated power consumption was 480 kWh/mt (436 kWh/short ton).[6] Between 1995 and 1997, an additional 12 mmt of electric arc furnace capacity was built.

Figure 1 shows steel production in the United States has fluctuated dramatically since 1970, when production was just below 120 mmt. Production peaked at 136 mmt in 1973 and fluctuated between 100 and 130 mmt until it crashed to 68 mmt in 1982. This crash was a result of a dramatic number of integrated mill closures. Since 1982, steel production has grown slowly, with two major declines from 1985 to 1986 and in 1991.

In 1995, steel production reached 95 mmt. Primary steel production using an inefficient open hearth furnace (OHF) dropped from 44 mmt in 1970 to 6 mmt in 1982. OHF use was phased out completely by 1992.

Primary steel production using a basic oxygen furnace fluctuated between 40 and 75 mmt between 1970 and 1995. Electric steelmaking more than doubled, growing from 18 to 38 mmt between 1970 and 1995.[3]

Energy use for the iron and steel industry (SIC 331, 332) has fluctuated from 2.6 EJ of final energy (2.8 EJ primary energy or 2.6 quads) in 1958 to 2.2 EJ of final energy (2.6 EJ primary energy or 2.5 quads) in 1994. Peak energy use occurred in 1973, when 3.9 EJ (4.4 EJ primary energy, or 4.2 quads) were used to produce steel.

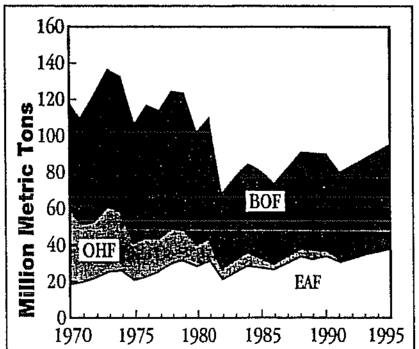

Figure 1 *U.S. steel production is shown by process (BOF, OHF and EAF) from 1970 to 1995 (in million metric tons). One short ton equals 0.907 metric ton.*

Between 1958 and 1994, the share of coal and coke used as energy sources dropped from about 75 to 65 percent of total fuels, followed by a drop in the share of oil from 10 to 2 percent. The share of natural gas used in the industry increased from 10 to 25 percent.

The share of electricity increased from 4 to 9 percent during the same period, in large part due to increased electric steel production. Carbon emissions trends followed energy use trends, with emissions of 68 mmtC in 1958, 103 mmtC in 1973 and 59 mmtC in 1994.[7]

Physical energy intensity (expressed as GJ/mt crude steel), defined as primary energy use per metric ton of steel produced, of U.S. steel production dropped 19 percent from 35.6 GJ/mt (30.6 MBtu/ton) to 28.8 GJ/mt (24.8 MBtu/ton) between 1958 and 1994.

Decomposition analyses indicate that about two-thirds of the decrease between 1980 and 1991 was due to efficiency improvements, while the remainder was caused by structural changes.[8]

Carbon intensity dropped from 0.88 mtC/mt to 0.64 mtC/mt during this period, reflecting the general decrease in energy use per metric ton of steel produced as well as fuel switching. The most important change was the growing use of scrap based electric arc furnaces for electric steel production, which grew from 17 to 39 percent of total steel production during this period.

Efficiency improvement can be explained mainly by the increased use of continuous casting, which grew from 0 percent in 1971 to 89 percent in 1994, and the closing of inefficient OHF steelmaking, which dropped from 30 percent in 1971 to 0 percent after 1991.

Despite these overall improvements, energy intensity [using U.S. Department of Energy (DOE) energy consumption statistics] of steel production in the United States increased slightly between 1991 and 1994. It grew from 27.7 GJ/mt (23.8 MBtu/ton) to 28.8 GJ/mt (24.8 MBtu/ton), reversing the long-term downward trend.[1] This increase is unexpected, based on trends in three key areas (increased share of EAF from 38 to 39 percent, retirement of all remaining OHFs and an increase in the use of continuous casting from 76 percent in 1991 to 89 percent in 1994).

Trends that may have contributed to the increased energy use include a move toward more extensively treated cold rolled steel and increased capacity utilization, leading to the use of older, less-efficient integrated steel mills.[9] Note that the reliability of statistical sources may affect the results.

INTERNATIONAL INTENSITY COMPARISONS

Energy intensities for eight of the world's largest steel producing countries show a general downward trend in most countries between 1971 and 1994. Iron and steel production is least energy intensive in South Korea, Germany, Japan and France and most energy intensive in China. Energy intensity of steelmaking in the United States dropped more than 20 percent between 1971 and 1994. As noted, the 1994 energy intensity is slightly higher than that in 1991, indicating a change in the longer term trend of decreasing energy use per metric ton of steel. Japan, Poland and France also show a slight increase in energy intensity in recent years.[9]

To provide an indication of how the energy intensity of the total iron and steel sector in the United States compares with operating plants with the lowest energy intensities globally, the "best practice" energy intensities first were determined for specific processes based on plants in operation in The Netherlands and Germany.[8] Production structure is defined by shares of BOF and EAF steelmaking, and by shares of slabs and hot rolled and cold rolled products produced. The energy intensity that would have been achieved in the United States in both 1991 and 1994 was calculated to produce the same mix of products that actually was produced in those years using the 1988 best practice energy intensities.

Figure 2 shows the comparison of the actual energy intensities and the best practice energy intensities for the United States in 1991 and 1994, as well as for six other countries in 1991. The horizontal axis indicates the share of EAF steelmaking in each country; EAF steelmaking is a much less energy intensive process, and countries with a higher share of this process would be expected to have lower overall energy intensities for production of steel.

As shown in Figure 2, China, Brazil, Poland and the United States have the largest potential energy savings, while France, Japan and, especially, Germany have lower potentials. The difference in the United States' best practice and actual energy intensities was about 11 GJ/mt (9.5 MBtu/ton) in both 1991 and 1994, despite the fact that the United States had the highest share of EAF steelmaking (38 percent in 1991 and 39 percent in 1994). When compared with best practice in other countries, U.S. energy use per metric ton of steel is high in the blast furnace, BOF (due to the lack of BOF gas recovery), reheat furnace and hot strip mill.[8, 10]

Figure 3 shows the relative changes in primary energy intensity in seven countries between 1980 and 1991, and shows those changes in the portion attributed to efficiency improvement and that attributed to structural change (i.e., changes in process and product mix). The left-most bar for each country represents the aggregate change in physical energy intensity between 1980 and 1991, while the middle and right-hand bars represent the contribution of efficiency and structural changes, respectively, to the overall change in physical energy intensity during the period.

Energy use for steel production in the United States dropped 17 percent from 1980 to 1991. Of this, a decline of 6 percent was due to structural changes like the shift to EAFs and 11 percent was due to efficiency improvements.[8] This analysis suggests that energy efficiency improved at a rate of about 1 percent per year in the United States over the period from 1980 to 1991.

ENERGY USE IN ELECTRIC STEELMAKING

In electric steelmaking, energy mainly is consumed in the EAF and rolling mill. On basis of the literature and statistics, the energy consumption was estimated in different steps of electric steelmaking. In 1994, EAF based mills produced 35.9 mmt of crude steel, and integrated mills produced 55.4 mmt of crude steel in the United States. The 1994 primary energy use in integrated steelmaking was estimated at 1,500 PJ (1.42 quads) or 3.5 times as high as in electric steelmaking (Table I).

For comparison, the total energy use and carbon emissions of the U.S. iron and steel industry in 1994 are shown. EAF shops produce approximately 20 percent of the total carbon emissions of the iron and steel industry (SIC 3312) (Table I).

ENERGY EFFICIENCY MEASURES

To more carefully analyze the potential for reducing energy use and carbon emissions from steelmaking in the United States, information was compiled on the costs, energy savings and carbon emissions reductions of a number of technologies and measures.

Worrell et al. (1998) provide a detailed description of each of these

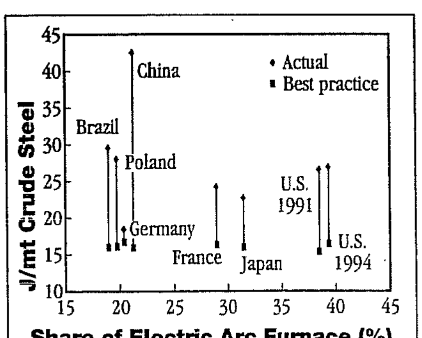

Figure 2 *Actual and best practice energy intensities are compared for selected countries in 1991 and 1994. Source: Price et al.[9]*

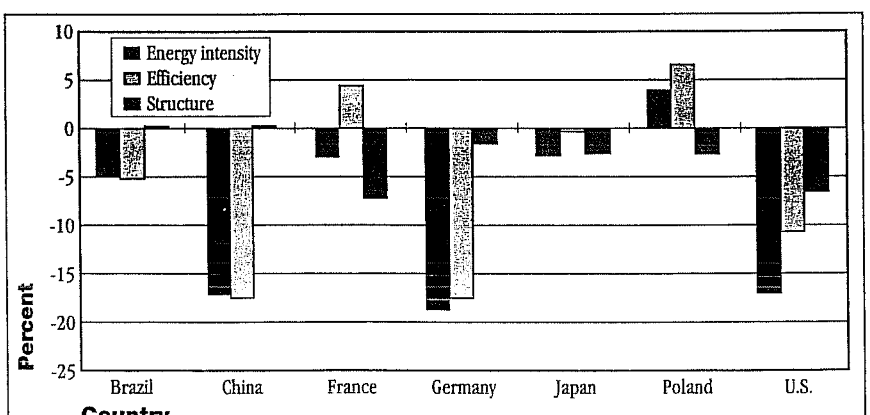

Figure 3 *The relative changes in energy intensity are shown between 1980 and 1991. The left-most bar represents the total change in energy intensity for the period. The middle bar provides the contribution due to changes in energy efficiency, and the right-hand bar the contribution due to changes in production structure.*

Table I *Estimated Energy Use (PJ) and Carbon Emissions (mmtC) in U.S. Electric Steel Production in 1994 [Electricity conversion efficiency is 32.5 percent. Carbon emission factors are 15.3 kg C/GJ (gas), 22.4 kg C/GJ (oil), 27 kg C/GJ (coal) and 50.5 kg/GJ for electricity.[5]]*

Process Stage	Fuel	Electricity	Primary Energy	Carbon Emissions
EAF	6	62	197	3.0
Casting	1	4	12	0.2
Hot rolling	102	22	170	2.4
Boilers	41	0	41	1.5
Others	12	–2	12	0.0
Total electric steelmaking	162	85	424	7.1
Total U.S. steel industry	1,455	147	1,925	35.8

technologies and measures, along with costs and energy savings associated with the technologies and measures and other related information.[2] The technologies and measures fall into two categories:

(1) State-of-the-art measures that are currently in use in steel mills worldwide
(2) Advanced measures that are either only in use in limited applications or under demonstration

In this section, only the state-of-the-art technologies and practices for electric steelmaking are described. For each measure, costs and energy savings are estimated per metric ton of crude steel produced in 1994. Then, the carbon emissions reductions are calculated based on the fuels used at the process step to which the technology or measure is applied.

Table II provides:

- Total throughput
- Fuel, electricity and primary energy savings per metric ton of crude steel
- Annual operating cost savings
- Retrofit capital costs per metric ton of crude steel
- Percentage to which the measure is applied nationally
- Carbon emissions reductions for each measure applied to the production of primary steel by EAFs

A detailed description of the individual measures is not possible within the limits of this paper. For a detailed description of the assumptions and sources used, refer to reference 2. Table II shows important energy efficiency measures are preventative maintenance (i.e., good housekeeping), improved process control, oxy-fuel burners, scrap preheating, thin slab casting and recuperative burners in reheating furnaces.

The measures can be ordered on the basis of cost effectiveness using conservation supply curves, which rank energy efficiency measures by their cost of conserved energy (CCE). They account both for the costs associated with implementing and maintaining a particular technology or practice, and the energy and costs savings associated with that option over its lifetime.

The CCEs are plotted in ascending order to create a conservation supply curve. This curve is a snapshot of all the total annualized cost of investment for all the efficiency measures being considered. The width of each option or measure (horizontal axis) represents the specific energy saved by that option. The height (vertical axis) shows the CCE.

The advantage of using a conservation supply curve is it provides a clear, easy-to-understand framework for summarizing a variety of complex information about energy efficiency technologies, their costs and the potential for energy savings. The curve will avoid double counting of energy savings, is independent of prices and also provides a comparable framework to compare with supply curves of energy production.

This conservation supply curve approach also has certain limitations. In particular, the potential energy savings for a specific sector depend on the measures listed and/or analyzed at a certain point in time. Additional energy efficiency measures or technologies may not be included in an analysis, so the savings may tend to be underestimated. The costs of efficiency improvements (i.e., initial investment costs plus operation and maintenance costs) does not include all the transaction costs for acquiring information needed to evaluate and choose an investment, and additional investment barriers may exist as well that are not accounted for in the analysis.[11, 12]

Many analysts use the internal rate of return (IRR) to rate the cost effectiveness of various investments, which is the value of the discount rate to make the net benefits stream equal to the initial investment. A key difference between CCE and IRR is that with an IRR, the fuel price for the analysis period is included in the calculation (since energy savings are quantified on a dollar basis). Therefore, the fuel price affects the evaluation of a measure. With the CCE calculation, changes in fuel prices do not change the CCE of a measure, but change the number of measures that are considered to be cost-effective.

For this analysis, a 30 percent discount rate was used, which reflects the steel industry's capital constraints and preference for short payback periods and high IRRs. An industry average weighted fuel cost is used in the calculation, based on energy data provided by the American Iron and Steel Institute (AISI) and cost data from the DOE-Energy Information Administration.[1]

A cost-effective energy savings of 104 PJ (0.1 quads) and carbon emissions reductions of 1.5 mmtC of carbon were identified for electric steelmaking in 1994. This represents 5 percent of total U.S. steelmaking energy use and 4 percent of total carbon emissions. Figure 4 ranks the electric steelmaking measures in a conservation supply curve, based on Table III.

Some of the main cost-effective measures for electric steelmaking include oxy-fuel burners, scrap preheating, improved process control in the EAF and preventative measures ranked by their cost of conserved energy, IRR and simple payback periods.

INNOVATIVE ENERGY EFFICIENCY POLICIES

As previously stated, energy use for steel production in the United States dropped 17 percent from 1980 to 1991, at a rate of about 1 percent per year. The trend between 1991 and 1994 is unclear, but seems to suggest a slowing in the efficiency improvement rate.

This detailed analysis of the U.S. iron and steel sector examined more than 45 state-of-the-art energy efficiency technologies and practices, and estimated energy savings, carbon savings, investment costs, and operation and maintenance costs for each of these measures.[2] For the total U.S. iron and steel industry, a cost-effective reduction potential of 3.7 GJ/mt (3.2 MBtu/ton) was identified.[2] This is equivalent to an achievable energy savings of 17 percent of 1994 U.S. iron and steel energy use and 18 percent of 1994 U.S. iron and steel carbon emissions.[2] It suggests sufficient potential still exists for increased efficiency improvement. However, recent slowing of the improvement rate indicates the need for innovative policies to reduce greenhouse gas (GHG) emissions, especially in light of the proposed U.S. commitments to reduce GHG

Table II *Energy Savings, Costs and Carbon Emissions Reductions for Energy Efficiency Technologies and Practices for Electric Steelmaking in the United States in 1994*[2]

	Throughput (mmt)	Fuel Savings (GJ/mt crude steel)	Electricity Savings (GJ/mt crude steel)	Primary Energy Savings (GJ/mt crude steel)	Annual Operating Cost Change (GJ/mt crude steel)	Retrofit Capital Cost (U.S. $/ mt steel)	Share of Production Measure Applied (percent)	Carbon Emissions Reductions (kg C/mt)
Steelmaking EAF								
Improved process control (neural network)	35.9	0.00	0.11	0.33	–1.00	0.95	90	4.6
Flue gas monitoring/control	35.9	0.00	0.05	0.17	0.00	2.00	50	2.3
Transformer efficiency – UHP transformers	35.9	0.00	0.06	0.19	0.00	8.30	40	2.6
Bottom stirring/stirring gas injection	35.9	0.00	0.07	0.22	–2.00	0.60	11	3.06
Foamy slag practice	35.9	0.00	0.07	0.20	–1.80	10.0	35	3.39
Oxy-fuel burners	35.9	0.00	0.14	0.44	–4.00	4.80	25	6.13
Eccentric bottom tapping on existing furnace	35.9	0.00	0.05	0.17	0.00	3.20	52	2.30
DC arc furnace	35.9	0.00	0.32	1.00	–2.50	3.90*	5	13.79
Scrap preheating – tunnel furnace (CONSTEEL)	35.9	0.00	0.22	0.66	–1.90	5.00	20	9.19
Scrap preheating – post-combustion (Fuchs)	35.9	–0.70	0.43	0.63	–4.00	6.00	20	8.78
Twin shell DC w/scrap preheating	35.9	0.00	0.07	0.21	–1.10	12.00	10	2.91
Casting								
Efficient ladle preheating	32.11	0.02	0.00	0.02	0.00	0.05	100	0.27
Thin slab casting	32.11	2.86	0.57	4.62	–31.33	134.29	20	63.57
Hot Rolling								
Process control in hot strip mill	31.31	0.26	0.00	0.26	0.00	0.61	88	3.59
Recuperative burners	31.31	0.61	0.00	0.61	0.00	2.18	88	8.38
Insulation of furnaces	31.31	0.14	0.00	0.14	0.00	8.73	30	1.92
Controlling oxygen levels and VSDs on combustion air fans	31.31	0.29	0.00	0.29	0.00	0.44	50	3.95
Energy efficient drives in the rolling mill	31.31	0.00	0.01	0.03	0.00	0.17	50	0.37
Waste heat recovery from cooling water	31.31	0.03	0.00	0.03	0.06	0.70	88	0.46
General Technologies								
Preventative maintenance	35.9	0.09	0.05	0.24	0.02	0.01	100	3.72
Energy monitoring and management system	35.9	0.02	0.01	0.06	0.00	0.15	100	0.93

* = New plant capital cost

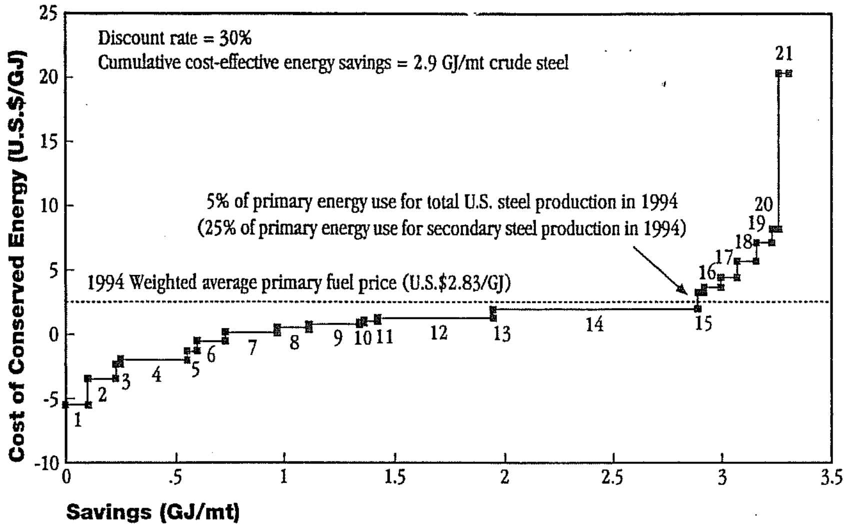

Figure 4 *This is the energy conservation supply curve for electric steelmaking in the United States (1994). Energy savings are depicted on the horizontal axis. On the vertical axis, the marginal CCE of each measure is shown. The numbers refer to Table III.*

Table III *Cost of Conserved Energy for Selected Measures in Electric Steelmaking (To convert to U.S.$/MBtu, multiply the primary CCE by 1.055)*

EAF Efficiency Measure	Primary CCE (U.S.$/GJ)	Primary Energy Savings (GJ/mt)	Cumulative Primary Energy Savings (GJ/mt)	Internal Rate of Return (percent)	Simple Payback Time (Years)
Oxy-fuel burners	–5.52	0.11	0.11	114	0.9
Scrap preheating, post-combustion shaft furnace (Fuchs)	–3.49	0.13	0.24	123	1.0
Bottom stirring/stirring gas injection	–2.42	0.02	0.26	191	0.2
Improved process control (neural network)	–2.08	0.30	0.56	223	0.5
DC arc furnace	–1.33	0.05	0.61	150	0.7
Scrap preheating – tunnel furnace (CONSTEEL)	–0.60	0.13	0.74	83	1.3
Preventative maintenance	0.10	0.24	0.98	>500	0.0
Controlling oxygen levels and VSDs on combustion air fans	0.46	0.14	1.12	105	0.5
Process control in hot strip mill	0.75	0.23	1.35	68	0.8
Efficient ladle preheating	0.87	0.02	1.37	59	1.0
Energy monitoring and management system	1.04	0.06	1.43	103	0.9
Recuperative burners	1.16	0.54	1.97	43	1.3
Energy efficient drives in the rolling mill	1.96	0.01	1.98	52	2.3
Near net shape casting/thin slab casting	1.98	0.92	2.91	31	3.0
Twin shell w/scrap preheating	3.33	0.02	2.93	30	3.5
Flue gas monitoring/control	3.68	0.08	3.01	27	4.3
Transformer efficiency – UHP transformers	4.47	0.08	3.09	22	5.2
Eccentric bottom tapping on existing furnace	5.81	0.09	3.17	17	6.8
Foamy slag practice	7.19	0.07	3.24	9	4.2
Waste heat recovery from cooling water	8.21	0.03	3.27	N/A	20.9
Insulation of furnaces	20.22	0.04	3.31	N/A	22.1

N/A = Not available

emissions to 7 percent below 1990 levels by the period from 2008 to 2012.

Environmental issues and energy use are strongly related. However, in the past, environmental and energy policies were separated. In a number of countries, more comprehensive views on environmental and energy policies have been developed. Legislation and regulation was the conventional approach to protect the environment. An alternative and effective approach for reducing use is to set high targets through mutual cooperation and voluntary agreements.[13] In some European countries (e.g., Denmark, Germany and The Netherlands), the use of voluntary or negotiated agreements has become popular in the industrial sector.

Voluntary agreements (VA) involving government and industry to meet GHG emission reduction objectives offer a policy option that could contribute to achieving these goals as well as being a cost-effective and flexible response to global climate change.[14] Great diversity exists among the various voluntary approaches, ranging from informal programs and self commitment to highly structured approaches.

The approaches in Denmark and The Netherlands are comprehensive policy systems, encompassing various stimulating policies. These programs employ a high degree of compulsion to participate.[14] To be successful, preliminary evaluation of VAs showed they need to include a clear definition of convincing objectives and targets. They also should have broad coverage and participation, flexible and cost-effective procedures to implement for both industry and government, and include comprehensive monitoring as well independent third party evaluation.[14]

The VAs in The Netherlands are an example of a highly structured approach, covering 80 to 90 percent of Dutch industrial energy demand. The iron and steel industry in The Netherlands was the first industry to sign a VA with the Dutch government.[13,15] The iron and steel industry in The Netherlands consists basically of one large integrated steel mill (producing 6 mmt annually of mainly flat steel products) and one minimill (producing approximately 250,000 mt annually of steel wire).

The VAs in The Netherlands aim at doubling the autonomous rate of energy efficiency improvement (i.e., improving energy efficiency by 20 percent between 1989 and 2000). Participants in VAs in The Netherlands have access to government programs for energy efficiency investments, are eligible for tax rebates, and have simplified procedures for environmental regulation compliance (e.g., permitting procedures). The VA was attractive to the steel industry because it made possible the development of a comprehensive approach to energy and environmental issues. Also, the agreement is familiar to the industry (i.e., contract), provides stability to the policy field, and, last but not least, is an alternative to future energy taxation.[13] The VA for industry in The Netherlands excludes energy used as feedstock. For the steel industry, this means that (part of) coke and coal used in the blast furnace is excluded from the efficiency improvement goals, underlining the need for clear definitions of the baseline and targets.

Generally, the VAs helped to increase awareness of energy efficiency and increase the implementation of practices and technologies.[16] They have led to a flexible and cost-effective approach to achieve the set goals through reducing noneconomic barriers to energy efficiency improvement.[17] In 1995, halfway through the period covered by the VA, the steel industry in The Netherlands was ahead of schedule and improved energy efficiency by 11 percent since 1989.[18] This mainly was achieved by reducing material losses, increasing coal injection in the blast furnace, BOF gas recovery, advanced cogeneration schemes, energy recovery, and good housekeeping and process control.[13,15] Today, the integrated plant in The Netherlands is among the most energy efficient and productive in the world.[19]

In the United States, the AISI has proposed a voluntary plan for GHG emission reduction. This plan aims to gradually reduce emissions through more effective utilization of materials, improve energy efficiency of processes and introduce new processes.[20] The AISI views a VA as an incentive to steelmakers over agreements with "binding limits and mandated reductions."[20] A VA, if based on the elements for success just discussed, could help to achieve the potentials for energy efficiency and productivity improvement determined in the study, while maintaining the needed flexibility to operate in a rapidly changing industrial environment.

CONCLUSIONS

In reviewing the industry as a whole, U.S. steel plants were found to be relatively old, with production rates that have fluctuated dramatically in the recent past. Between 1958 and 1994, physical energy intensity for iron and steelmaking (SIC 331, 332) dropped 19 percent from 35.6 GJ/mt (30.6 MBtu/ton) to 28.8 GJ/mt (24.8 MBtu/ton). Meanwhile, carbon intensity (i.e., carbon emissions per metric ton of steel) dropped 27 percent from 0.88 mtC/mt to 0.64 mtC/mt. Compared with other large steel producers, the United States still tends to have higher energy intensities and a large technical potential to achieve best practice levels of energy use for steel production.

This detailed analysis of the U.S. iron and steel sector examined more than 45 specific energy efficiency technologies and measures, and estimated energy savings, carbon savings, investment costs, and operation and maintenance costs for each of these measures. Based on this information, a conservation supply curve for U.S. iron and steelmaking was constructed that found a total cost-effective reduction of 3.7 GJ/mt (3.2 MBtu/ton), equivalent to an achievable energy savings of 17 percent of 1994 U.S. iron and steel energy use and 18 percent of 1994 U.S. iron and steel carbon emissions.

In electric steelmaking, 20 measures were identified that could result in savings equivalent to 25 percent of the estimated 1994 primary energy consumption. In 1997, the (weighted) average age of EAF furnaces was 24 years. New EAF based mills are being constructed in the United States, resulting in lower future energy consumption in electric steelmaking. However, potential improvements remain in existing mills.

Innovative policy instruments may help to implement the technologies and practices identified in this analysis. The VA is an example of an innovative policy instrument that could accelerate the uptake of efficient practices and technologies, while maintaining flexibility and increasing competitiveness.

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